



Calhoun: The NPS Institutional Archive

Theses and Dissertations

Thesis Collection

1999-03

A multi-service location-allocation model for military recruiting

Martin, Paul E.

Monterey, California: Naval Postgraduate School

<http://hdl.handle.net/10945/13625>



Calhoun is a project of the Dudley Knox Library at NPS, furthering the precepts and goals of open government and government transparency. All information contained herein has been approved for release by the NPS Public Affairs Officer.

**Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943**

<http://www.nps.edu/library>

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A MULTI-SERVICE LOCATION-ALLOCATION MODEL FOR MILITARY RECRUITING

by

Paul E. Martin

March 1999

Thesis Advisor:
Second Reader:

Kevin R. Gue
Robert F. Dell

Approved for public release; distribution is unlimited.

19990423 082

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1999		3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE A MULTI-SERVICE LOCATION-ALLOCATION MODEL FOR MILITARY RECRUITING				5. FUNDING NUMBERS	
6. AUTHOR(S) Martin, Paul E.					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.					
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (maximum 200 words) We develop a mixed integer non-linear program, MS-LOCAL, to help the Department of Defense decide where to locate recruiting stations and how to allocate recruiters to those stations. The goal of MS-LOCAL is to obtain the greatest number of enlisted recruits for the lowest possible cost. We solve MS-LOCAL in two forms: one that minimizes cost subject to production goals (in number of recruits), and a second that maximizes production subject to a budget constraint. We illustrate MS-LOCAL with data from the Jacksonville, Denver, and Boston metropolitan areas using a production function recently developed for all zip codes in the United States; the production function estimates recruits obtained for given recruiting stations and recruiter allocations. Our results show that a combination of single-service and joint-service stations is most effective in minimizing cost and maximizing production. Compared to the current configurations of stations and recruiters in the metropolitan areas, MS-LOCAL estimates that cost savings of 10-32% or production increases of 2-8% are possible.					
14. SUBJECT TERMS Optimization, Mixed Integer Programming, Facility Location, Multi-Objective Programming, General Algebraic Modeling System (GAMS)				15. NUMBER OF PAGES 60	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified		20. LIMITATION OF ABSTRACT UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39

Approved for public release; distribution is unlimited.

A MULTI-SERVICE LOCATION-ALLOCATION MODEL FOR MILITARY RECRUITING

Paul E. Martin
Lieutenant, United States Navy
B.S., The Pennsylvania State University, 1988

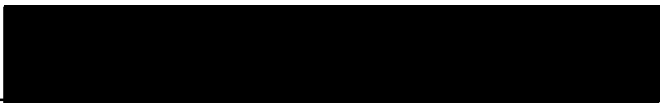
Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 1999


Author:


Paul E. Martin

Approved by:


Kevin R. Gue, Advisor


Robert F. Dell, Second Reader


Richard E. Rosenthal, Chairman, Department of Operations
Research

ABSTRACT

We develop a mixed integer non-linear program, MS-LOCAL, to help the Department of Defense decide where to locate recruiting stations and how to allocate recruiters to those stations. The goal of MS-LOCAL is to obtain the greatest number of enlisted recruits for the lowest possible cost. We solve MS-LOCAL in two forms: one that minimizes cost subject to production goals (in number of recruits), and a second that maximizes production subject to a budget constraint. We illustrate MS-LOCAL with data from the Jacksonville, Denver, and Boston metropolitan areas using a production function recently developed for all zip codes in the United States; the production function estimates recruits obtained for given recruiting stations and recruiter allocations. Our results show that a combination of single-service and joint-service stations is most effective in minimizing cost and maximizing production. Compared to the current configurations of stations and recruiters in the metropolitan areas, MS-LOCAL estimates that cost savings of 10-32% or production increases of 2-8% are possible.

DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While an effort has been made within the time available to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

I.	INTRODUCTION	1
A.	BACKGROUND FOR OUR STUDY	2
B.	PROBLEM STATEMENT AND APPROACH	3
II.	LITERATURE REVIEW	5
A.	RELATED COMMERCIAL APPLICATIONS	5
B.	MILITARY APPLICATIONS	8
C.	OUR PROBLEM	9
III.	A LOCATION-ALLOCATION MODEL	11
A.	THE PRODUCTION MODEL	11
1.	Classifying Recruits	11
2.	An Econometric Model	12
B.	MODELING RECRUITING COSTS	15
C.	MS-LOCAL	16
1.	Notation	17
2.	The Min-Cost MS-LOCAL	19
3.	The Max-Production MS-LOCAL	20
D.	SOLUTION METHODOLOGY	21
1.	Obtaining Integer Recruiters	21
2.	Reducing Problem Size	23
IV.	IMPLEMENTATION AND RESULTS	25
A.	DATA	25
B.	RESULTS	27
1.	Jacksonville	28
2.	Denver	30
3.	Boston	32
C.	FINDINGS	34

V. SUMMARY AND CONCLUSIONS	37
LIST OF REFERENCES	39
INITIAL DISTRIBUTION LIST	41

LIST OF FIGURES

1.	Recruit Quality Classification Matrix	12
2.	Piecewise Linear Approximation of Zip Code 32068 (Navy Production)	17
3.	Current Configuration for Jacksonville.	29
4.	MS-LOCAL Configuration for Jacksonville (Recruiter Cost = \$10K). .	29
5.	Current Configuration for Denver.	30
6.	MS-LOCAL Configuration for Denver (Recruiter Cost = \$10K). . . .	31
7.	Current Configuration for Boston.	32
8.	MS-LOCAL Configuration for Boston (Recruiter Cost = \$10K). . . .	33

LIST OF TABLES

I.	Error of Piecewise Linear Approximation for Zip Code 32068 (Navy Production)	18
II.	Coefficients for the Production Function	26
III.	Coefficients for Interaction Between Services	27
IV.	Results for the Jacksonville Metropolitan Area.	28
V.	Results for the Denver Metropolitan Area.	31
VI.	Results for the Boston Metropolitan Area.	33
VII.	Percent of Stations Recommended for Collocation	34
VIII.	Average Number of Recruiters per Station.	35

ACKNOWLEDGMENTS

This thesis is dedicated to my family and the unlimited support they provided me during its completion. I would also like to thank Professors Kevin R. Gue and Robert F. Dell for their hard work, dedication and support in helping me complete this thesis. Lieutenant Michael J. "Reggie" Hammond also deserves special thanks for laying the groundwork for the optimization model.

EXECUTIVE SUMMARY

Recently, there has been a great deal of news concerning the number of enlisted recruits that the military services have been able to enlist for active duty service. A foreseeable response by the Department of Defense (DoD) is an increase in the number of recruiting stations, active duty recruiters, and advertising budgets to enable the military services to reach their annual recruiting goals for enlisted personnel. The DoD currently lacks a model that optimally locates military recruiting stations and allocates recruiters for each branch of service to those stations. We address these issues by formulating an optimization model, MS-LOCAL, that locates recruiting stations and allocates recruiters for multiple services in a geographical area.

The goal of MS-LOCAL is to locate stations and allocate recruiters to get the greatest number of A-cell recruits (those having a high school diploma and scoring at or above the fiftieth percentile on the military entrance exam) for the lowest possible cost. MS-LOCAL comes in two forms: one that minimizes cost subject to production goals and a second that maximizes production subject to a budget constraint. The production function estimates recruits obtained for given recruiting stations and recruiter allocations. MS-LOCAL uses a production function recently developed for all zip codes in the United States and it includes terms for the effect of one service's recruiting efforts on another service's production and incorporates the practice of services sharing costs by using common recruiting stations.

The problems are large mixed integer non-linear programming problems, and therefore quite difficult to solve. Our implementation transforms them into mixed integer linear programming problems by using a piecewise linear approximation of the quadratic production function and using a heuristic approach to obtain integer values for recruiters. Although our model is capable of addressing all four military services, only data for the Army and Navy were available at the time of this research. We illustrate the use of MS-LOCAL with data from the Jacksonville, Denver and

Boston metropolitan areas representing small, medium, and large areas, respectively. We choose metropolitan areas as our unit of study because metro areas define common boundaries, whereas Navy districts or Army battalions do not.

Our results show that a combination of single-service and joint-service stations is most effective in minimizing cost and maximizing production. Compared to the current configuration of stations and recruiters in the metropolitan areas, our model shows that cost savings are possible while reaching the same production goals (in number of recruits) and that production can be increased within current budget constraints.

Our results suggest that equivalent production levels for the three metropolitan areas are reachable with cost savings between 10% and 32% less than the current configuration of stations and recruiters. Solutions to the max-production form of the model show that production increases between 1.6% and 7.8% recruits per year are possible, depending on the metropolitan area.

Our model has several potential uses for DoD.

- It can be used by the Joint Recruiting Facilities Committee to help decision-makers in joint planning conferences.
- Individual services can use the model to locate stations in a region.
- The model can select the best sites for new stations among a set of candidate locations.
- A service can analyze many metropolitan areas and classify them based on how far each is from the optimal configuration. This would help prioritize regions for more detailed station analysis.
- The model can address broader policy questions, such as the best number of recruiters per station.

I. INTRODUCTION

Recently, there has been a great deal of news concerning the number of enlisted recruits that the military services have been able to attract for active duty service. A New York Times article declared that, "many officials believe the armed services face a deeper problem and one more difficult to solve: The military, simply put, no longer looms very large in young people's lives and families" (Myers, 1998). In fact, military recruiting commands are struggling to achieve their required number of recruits. The fiscal year 1998 recruiting goals for all four branches of service totaled nearly 200,000 people. While the Air Force and Marine Corps were able to meet their goals, both the Army and Navy fell short. The Army missed its goal of 72,600 new soldiers by just one percent overall, but it fell far shorter in enlisting recruits for harder to fill specialties. For the first time since the advent of the all-volunteer force in 1973, the Navy failed to meet its recruiting goals, falling 12 percent short of its goal of 55,300 enlisted recruits (Associated Press, 1998).

These shortages have many causes, but most people would agree on a common few. Foremost, the U. S. economy is thriving. In the past few years, unemployment rates have been at some of the lowest levels since the Vietnam era. The number of people graduating from high school and directly entering college is 70 percent. A decade ago, less than half of those graduating from high school went straight to college (Myers, 1998). Also, since the number of personnel in the military has decreased 32 percent since the late 1980's, there are not as many veterans in today's population. This has caused a decline in the number of people recruiters commonly call "influencers". These are relatives, friends, coaches, teachers or others with military service who often encourage people to join the service.

The military services have been examining ways to improve recruiting, including increasing the number of recruiters, adding more stations across the country, and increasing the amount of advertising in all media types. Our work addresses the first

two of these areas.

A. BACKGROUND FOR OUR STUDY

In 1994, Congress tasked the General Accounting Office (GAO) to identify areas where military recruiting costs could be reduced without affecting the ability to meet recruit requirements. GAO (1994) argued the productivity of recruiters in many areas did not justify the cost of acquiring, operating, and maintaining offices. GAO also implied that redistributing recruiters could save more than \$13 million in annual facility costs without adversely affecting the services' production of recruits.

Aided by GAO's findings, Congress developed *Sec 32, Study Regarding Joint Process for Determining Location of Recruiting Stations*, of the National Defense Authorization Act for 1996, which directed the Secretary of Defense to conduct a study on (1) using a joint process among the Armed Forces for determining the location of recruiting stations and the number of military personnel required to operate such stations, and (2) basing such determinations on market research and analysis conducted jointly by the Armed Forces. As a result of this study, the Office of the Secretary of Defense tasked the Naval Postgraduate School to develop models to predict cost and production effects of management decisions to close, open and relocate recruiting stations (Office of the Assistant Secretary of Defense (Force Management Policy), 1996a).

In 1998, the DoD spent more than \$1.4 billion on recruiting (Associated Press, 1998). With recruiting requiring such a substantial investment, the DoD wants to locate its recruiting stations as effectively as possible in order to meet recruiting goals at minimum cost. Currently, the DoD does not possess a means for optimally locating its recruiting stations and the recruiters that operate them. Each service has its own methodology for locating recruiting stations and estimating the number of recruits in a market area. While some of the services have mathematical models to aid in their decision making, others do not. Services that do have models use single-service

models that do not include the effects of individual services on production of another service.

B. PROBLEM STATEMENT AND APPROACH

Our problem is to determine, for a given region, the locations of the recruiting stations and the number of recruiters of each service to assign to these stations. We consider two approaches to solve the problem — one that achieves target production levels at minimum cost, and another that maximizes production subject to a budget constraint. We formulate the problem as a mixed integer linear program and solve this problem with a two-stage algorithm. We call our model the Multi-Service Location-Allocation model, or MS-LOCAL.

We test MS-LOCAL using data from the Army and Navy recruiting stations in the Jacksonville, Denver and Boston metropolitan areas. Our results suggest that the DoD could reduce recruiting costs by jointly planning the locations of Army and Navy stations.

The rest of the thesis is organized as follows. Chapter II provides a literature review on models used to solve competitive location-allocation problems for commercial firms and the military. Chapter III describes the forecasting of enlistment contracts, the costs associated with recruiting operations, and the MS-LOCAL formulation. Chapter IV shows and describes our implementation of MS-LOCAL and the results from the Jacksonville, Denver, and Boston metropolitan areas. Finally, Chapter V summarizes the thesis and discusses possible areas for future research.

II. LITERATURE REVIEW

We discuss the literature for site location models developed for use in private industry and those developed for the military services. For private industry, the site selection models primarily come in two forms: The first is a single site location model used to locate a distribution warehouse or retail location. The second type determines multiple site locations, such as for franchise outlets. Eiselt et al. (1993) conduct a review of more than 100 titles on location models and provide a taxonomy for classifying these models.

A. RELATED COMMERCIAL APPLICATIONS

Prior to 1980, most site location models located a single facility or outlet. These models do not apply to our problem because we must locate multiple recruiting stations within a geographic area. Among the following models, only Domich et al. (1991) is known to have been put to practical use in industry.

Achabal et al. (1982) develop a multiple store location model (MULTILOC) extending the Multiplicative Competitive Interactive (MCI) model to the multistore location problem. The MCI model (see Nakanishi and Cooper, 1974) is one of the first models to incorporate a competitive environment in the evaluation of potential store locations. The goal of MULTILOC is to identify locations for multiple outlets under single ownership. However, the model does not consider how new outlets affect the performance of existing outlets. MULTILOC is a mixed integer non-linear program, which the authors solve using a random search procedure and an interchange heuristic.

Site selection models concerning franchises closely parallel the issues involved with the location of recruiting stations, in that the viewpoints of the franchisor and franchisees are similar to those of the DoD and the individual services. Zeller et al. (1980) develop a mixed integer non-linear model to resolve locational conflicts within a franchise system, specifically those that exist between the franchisor, the existing

franchisees and those that wish to open a new outlet. The objective of each model is to maximize profits for the individual(s) concerned. However, the optimal solution for the franchisor may not be optimal for the individual franchisees. The success of a new outlet may be due to pulling customers and profits from those franchisees already in existence. To illustrate that market penetration and location goals of the members of a franchise system coincide only under a limited set of circumstances, the authors use data from a fast food franchise for analysis.

Pirkul et al. (1987) argue that the model discussed in Zeller et al. (1980) is "likely to be computationally intractable in many real-life situations", because it does not consider the possibility of opening a store owned and operated by the parent company itself, even though this can be the most desirable alternative for certain situations, nor does it consider regional warehouses which, in practice, normally carry out the distribution of merchandise. The objective function for the integer programming model in Pirkul et al. (1987) is to maximize the expected returns to the franchisor generated by both company and franchisee owned outlets subject to the constraints on the total capital budget and individual warehouse capacities. The authors report results on hypothetical data consisting of up to 300 potential store locations and 20 regions that solve in less than 145 CPU seconds on a PRIME 9955 minicomputer running PRIMOS 19.4.5.

One can view new recruits signing enlistment contracts like a franchise views sales. Ghosh and Craig (1991) state that there are two ways for a franchise to increase sales: to increase the number of outlets or to increase the sales of existing outlets. They state that increasing the number of outlets is more desirable because its impact is more rapid and some economies of scale can be attained. In fact, existing franchise outlets belonging to the same chain benefit from the contributions that the new franchisees make towards advertising and market share. Of course, recruiting is different than franchising in that the objective is to achieve a target number of recruits at minimum cost, rather than maximizing profits.

In their model, Ghosh and Craig (1991) use the concept of reservation distance, which is defined as the maximum distance a person is willing to travel in order to visit a store. While this makes sense for franchises that do not deliver their products (oil-change outlets, fast-food restaurants), these reservation distances are not as relevant for military recruiting. GAO (1994) states "[military] officials told us that the percentage of accessions gained from walk-in traffic is quite low". The military services believe that face-to-face contact with a military recruiter is necessary to actually enlist applicants. This contact is made by several means, such as making presentations at area high schools, canvassing places of employment and shopping malls, and contacting prospective enlistees directly. The majority of these methods occur outside of the recruiting station (GAO, 1994). Ghosh and Craig use data from two fast food chains to illustrate the results of their model.

Current and Storbeck (1994) develop a site location model, multiobjective integer programming model, for franchise systems that deliver a good or service. The objective of the franchisor is to locate outlets to maximize total market share or the total number of outlets so that each individual franchise has enough demand to obtain normal profits. The objective of the franchisee, which can be in conflict with that of the franchisor, is to locate its particular outlet to maximize its individual market share. The author's multiobjective model generates a set of franchise location schemes that demonstrate the trade-offs between the franchisor's and the franchisee's locational objectives using a 21 node sample problem. The franchisor is then expected to evaluate each of these alternate location schemes in terms of other criteria such as pricing strategies for the various sites, total costs, likelihood of the individual franchisee's success, total profit, and the effects on the response of competitors.

In each of the franchise models above, the costs associated with the location of new outlets are not discussed in detail. Most models maximize revenue, profit, or expected return but do not mention any of the costs associated with franchise location. An exception to this is Domich et al. (1991). Their integer programming

model selects locations for Internal Revenue Service (IRS) Posts-of-Duty (POD) by minimizing facility and travel costs to both the IRS staff and taxpayers. To compute the different costs, the authors incorporate separate costs for opening and closing a POD, cost of a round-trip from a zip code serviced by a POD to the POD, and the cost of office space for a zip code. The authors show results for the Jacksonville district, consisting of 872 zip codes. The 20 existing POD in this district are fixed and the model solves for the best two stations out of four candidates. It takes 1 minute and 40 seconds, on an IBM PC/AT (6 MHz) to obtain the solution. The authors report that 10 of approximately 60 IRS districts throughout the country use the model to locate facilities within their areas of responsibility.

B. MILITARY APPLICATIONS

Doll (1992) develops two non-linear models to optimally allocate recruiters and facilities for the 12th Marine Corps District at the county level. This district consists of approximately 301 counties, 419 recruiters and 247 recruiting facilities. The objective is to maximize the total population of enlistable individuals reachable from a reduced number of existing recruiting stations. An underlying assumption in this model is that no new facilities are allowed. The production function estimates the number of accessions based on linear regression.

Addressing a location problem, but at a higher level in the military chain of command, Celski (1992) develops a model for realigning the Army Recruiting Command. The mixed integer linear programming model realigns recruiting companies within the boundaries of each recruiting battalion. The objective is to minimize the distance between the company headquarters and its assigned counties measured in distance as well as the potential of the estimated market for enlistments. Celski (1992) conducts analysis on the Raleigh, North Carolina Recruiting Battalion using estimates for the production function based on linear regression. The average CPU time to realign this battalion is 15 minutes using a 80486-33 MHz personal computer.

Schwartz (1993) and Lawphongpanich et al. (1992) develop models for two problems to align the recruiting structure for the Navy Recruiting Command. The first problem is to decide, within a recruiting district, which recruiting stations should remain open and how many recruiters should be assigned to them, with the objective of maximizing the number of accessions for active duty recruiters. They formulate this as a mixed integer non-linear program and solve it by decomposition using four subproblems. They solve the subproblems sequentially, and the solution is empirically shown to produce near-optimal results (within 10%) in approximately 286 CPU seconds on an Amdahl 5990-500 computer. They use estimated production based on a log-linear regression model of Bohn and Schmitz (1992). These models are currently in use at the Navy Recruiting Command.

To determine the location and staffing levels of Army recruiting stations within a recruiting battalion, Lawphongpanich et al. (1994) develop an optimization model to maximize the total number of annual enlistments. They formulate this as a mixed integer non-linear program and solve it with a heuristic similar to Schwartz (1993). The model takes into account that the Army Recruiting Command is not only responsible for recruiting for its active duty component but also for its reserve component. They estimate production using Poisson regression in conjunction with Data Envelopment Analysis (DEA). They formulate two production functions in this study. The first is average production, which uses zip codes belonging to all recruiting stations in the region. The second is the efficient production function. It uses zip codes that correspond to efficient recruiting stations according to DEA. To illustrate the model, the authors solve the Albany battalion problem (77,539 binary variables and 79,756 constraints) in 7.5 minutes on an Amdahl 5990-500 computer.

C. OUR PROBLEM

The problem we address has the following distinguishing characteristics. First, we use detailed recruiting station cost data, including costs directly associated with

opening a station in a zip code, costs incurred from another service joining an established station, and the costs of the recruiters themselves. Moreover, the total number of stations and recruiters is an output of MS-LOCAL rather than an input, as in Schwartz (1993) and Lawphongpanich et al. (1994).

The second area is the competition associated with the military services. It is likely that if a person's interest is in military service then that person is a candidate for more than one branch of service. This implies a competition between services because they are all, primarily, after the same market. This may cause services to establish single service locations in order to minimize competition. However, if services cooperate by collocating, each can reduce its total costs.

III. A LOCATION-ALLOCATION MODEL

We describe our formulation to solve the problems of locating recruiting stations and determining the number of recruiters of each service to be assigned to these stations. The first section discusses the recruit production model along with the method of classifying recruits and the econometric model used. The second section discusses the costs associated with recruiting for the DoD. The third section provides the formulations for our minimum cost and maximum production forms of MS-LOCAL. The final section discusses solution methodologies for solving the two forms.

A. THE PRODUCTION MODEL

The number of recruits the DoD enlists each year is primarily a function of the number of stations and recruiters that the services have located throughout the country. As such, the military services differentiate their target market into several groups.

1. Classifying Recruits

The DoD recruiting commands classify potential enlistees based on two primary factors: education and score achieved on the military entrance exam. Education is further divided into two groups. The first contains those who currently possess a high school diploma or are high school seniors expecting to graduate. The second contains those who do not currently have a high school diploma and do not expect to get one in the future.

Each prospective recruit for the armed services takes the military entrance exam, the Armed Forces Vocational Aptitude Battery (ASVAB) (Office of the Assistant Secretary of Defense (Force Management Policy), 1996b). Based on the results of this test, recruits fit into one of the eight mental group categories shown in Figure 1.

RECRUIT QUALITY MATRIX

Percentile	Mental Group	HIGH SCHOOL Diploma Graduate	NON HIGH SCHOOL Diploma Graduate	
99	I	A	B	
93	II			
65	IIIU			
50	IIIL			
31	IVC	CI	D	
21	IVA			
16	IVB	NOT BEST QUALIFIED		
10	IVc	INELIGIBLE		
0	V			

Figure 1. The recruit quality classification matrix groups recruits according to their results from the ASVAB. Those recruits with a high school diploma and ASVAB score above the fiftieth percentile are known as the A-cell.

DoD is most interested in 17-21 year old males with a high school diploma who score at or above the fiftieth percentile on the military entrance exam. This group is known as the A-cell.

2. An Econometric Model

We use the production function given in Hogan et al. (1998). The statistical model they develop for estimating the number of A-cell male enlistment contracts uses the following notation:

Indices:

- a general attributes for a zip code,
- l zip codes with a recruiting station,
- s, s' branches of military service, and
- z zip code.

Elements of the index a are:

- The per-capita **income** of the zip code,
- The **population** of 17–21 year olds in the zip code,
- The **area** covered by a zip code in square miles,
- The indicator variable **urban**,
- The indicator variable **suburb**,
- The indicator variable **hs1**(equals 1 if the zip code has exactly 1 high school),
- The indicator variable **hs2**(equals 1 if the zip code has 2 or more high schools), and
- The **population density** of 17–21 year olds in the zip code.

The remaining elements in the regression equation are:

- $\beta_{s's}^{dist}$ coefficient for the effect of distance to station of service s' on service s production (accessions/mile/one-way trip to zip code),
- $\beta_{s's}^{sh1}$ coefficient for the effect of service s' share on service s production (accessions/recruiter share),
- $\beta_{s's}^{sh2}$ coefficient for the effect of service s' share squared on service s production (accessions/recruiter share squared),
- $\beta_{s's}^{sta}$ coefficient for the effect of s' station in the zip code on service s production (accessions),
- β_{sz}^a coefficient for attribute a in zip code z for service s (accessions/units for attribute a),
- β_s^{shxa} coefficient for the effect of service s share and attribute a interaction (accessions/recruiter share-units for attribute a),

- $\beta_s^{sta a}$ coefficient for the effect of a station of service s and attribute a interaction (accessions/units for attribute a),
 β_s^{jsta} coefficient for the effect of a joint station for service s (accessions),
 d_{zl} Euclidean distance from the centroid of zip code z to station l (miles/one-way trip to zip code),
 v_z^a value of attribute a in zip code z (units vary by attribute),
 H_{szl} recruiter share for service s assigned to station l in zip code z (recruiters for zip code z /recruiters at station l),
 W_l one, if station l is a joint station,
 X_{sz} one, if service s has a station in zip code z , and
 Y_{szl} one, if zip code z is assigned to station l for service s .

The production function for recruit production for service s in zip code z is:

$$\begin{aligned}
 P_{sz} = & \sum_{s'} \sum_l \left(\beta_{s's}^{dist} d_{zl} Y_{szl} + \beta_{s's}^{sh1} H_{szl} + \beta_{s's}^{sh2} H_{szl}^2 + \beta_{s's}^{sta} X_{sz} \right) \\
 & + \sum_a \left(\beta_{sz}^a v_z^a \right) + \sum_a \sum_l \left(\beta_s^{shxa} H_{szl} + \beta_s^{staxa} X_{sz} \right) + \sum_l \beta_s^{jsta} W_l.
 \end{aligned}$$

To estimate the effect of recruiters on production at the zip code level, Hogan et al. (1998) define the concept of recruiter *share* to mean the “fraction of a recruiter” dedicated to a zip code, that is, the population-weighted portion of all recruiters assigned to the parent station. For example, if a station has 3 recruiters and the population in a zip code is 1/10 the population of 17–21 year olds in all the station’s responsible zip codes, the zip code has recruiter share equal to 0.3. The intuition is that a more populous zip code probably receives more attention by a recruiter, and therefore his effect on production is greater.

To model the notion of diminishing returns of recruiter share in a zip code (that is, that the effect of increasing share from 0–0.5 is likely greater than increasing

from 9.5–10), Hogan et al. (1998) construct a quadratic relationship between recruit production and recruiter share.

Finally, we note that the production function is concave:

Theorem 1 *The production function P_{sz} is concave.*

Proof: The Hessian of P_{sz} is negative semi-definite because the only nonzero elements are $\partial^2 P_{sz} / \partial^2 H_{szl} = -2\beta_{ss}^{sh2}$ for all s . Since H_{szl} is a positive variable and $\beta_{s's}^{sh2}$ is negative for all s' and s , the production function is concave (Bazaraa et al., 1993).

□

B. MODELING RECRUITING COSTS

We group costs into 4 areas: the costs to open stations, the costs of services joining the stations, the costs of recruiters, and the costs associated with travel.

We assume that the cost of opening a station includes the cost of the first station “joining” it. This would include such costs as the lease, utilities, and parking. If a second service is collocated at the station, we assume an additional charge equal to 80% of the cost of the initial station opening. The amount is less because we expect some savings due to common areas such as hallways, bathrooms, and the like. (Preliminary results from cost models being developed by other researchers at the time of our thesis suggest that our model of cost savings is approximately correct. In any event, more detailed cost models can be incorporated easily into our optimization model.) Based on a preliminary study by Hogan (1998a) for the Atlanta metropolitan area, we use a one-service station cost of \$12,000 annually.

The cost of a recruiter can be viewed in two different ways, depending on whether or not the recruiter’s salary is included. One might view the salary as sunk cost to the DoD because if not recruiting, the person would be assigned elsewhere. In this case, we estimate a recruiter’s marginal cost, which is due to such expenses as lunches for recruits, laptop computers, and training costs, to be approximately

\$10,000 per year (Soutter, 1999). In the second case, one might view salary as part of recruiting costs, and we use recruiter cost of \$40,000 per year.

The final cost area is travel cost. The portion of time recruiters spend on the road varies according to the location of high schools, population density, and other factors. Hogan (1998b) estimates the costs of travel for recruiters with a simple regression using data from Navy recruiting districts. He assumes the miles driven are a function of the total distance from a station to all of the zip codes in its territory, and the population of those zip codes (recruiters are more likely to travel to populous zip codes than non-populous). The miles M_l driven from station l are:

$$M_l = 0.212885 \sum_z d_{zl} p_z,$$

where d_{zl} is the distance to station l from zip code z in its territory and p_z is the population in that zip code. We multiply M_l by the standard cost per mile c_{mile} (\$0.31) to obtain annual travel cost.

C. MS-LOCAL

The goal of our model is to locate stations and allocate recruiters to get the greatest number of A-cell recruits for the lowest possible cost. The minimum cost form of MS-LOCAL seeks the least cost configuration of stations and recruiters, such that each service achieves its target production level. The maximum production form of MS-LOCAL seeks a configuration of stations and recruiters that maximizes A-cell recruits, subject to a budget constraint.

Each form includes terms for the effect of one service's recruiting efforts on another service's enlistment contracts. We also incorporate the practice of multiple services sharing costs by using common recruiting stations.

Because the production function P_{sz} is non-linear, our formulation would be a large mixed integer non-linear programming problem, and therefore quite difficult to solve. To deal with this, we construct an approximation \bar{P}_{sz} of the original production

Jacksonville: Navy, Zip Code 32068

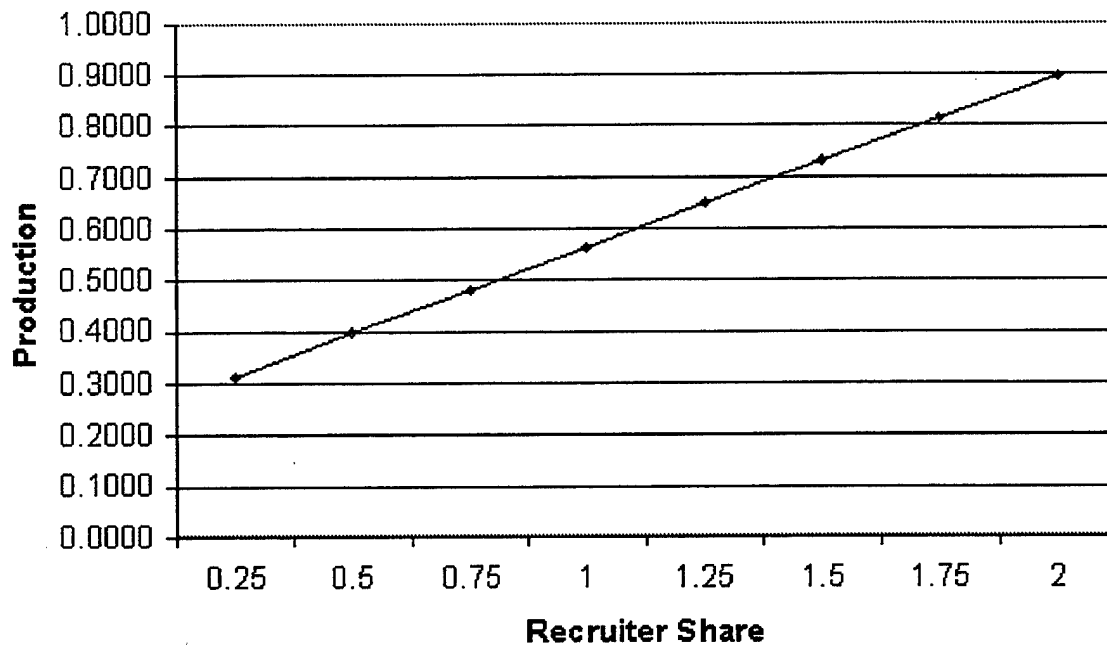


Figure 2. The piecewise linear approximation of zip code 32068 (Navy production) is shown above. The quadratic production function is nearly linear in this case.

function with a piecewise linear function having break point values for recruiter share H_{szl} of 0.25, 0.5, 1.0 and 2.0. Figure 2 shows the approximation for zip code 32068 (Navy production) from the Jacksonville metropolitan area. Notice that the curve in Figure 2 is almost linear, and therefore only a small amount of error is induced from the approximation. Table I shows the errors for the midpoints of three segments of the approximation. Our analysis of several other zip codes in the other metro areas produces similar, small errors.

1. Notation

The notation for our model is:

Recruiter Share	Estimated Production	Approximation	Error
0.375	0.3542	0.3542	0.0
0.75	0.4811	0.4808	0.0003
1.5	0.7314	0.7274	0.004

Table I. The error between the quadratic production function and the piecewise linear approximation for zip code 32068 (Navy production) for the midpoints of the piecewise segments.

Indices:

- a general attributes for a zip code,
- l zip codes with a recruiting station,
- s, s' branches of military service, and
- z zip code.

Data:

- B_s recruiting budget (\$/year),
- c_{1l} annual cost of operating a recruiting station at location l (\$/year),
- c_{2l} annual cost of a second service to join the station at location l (\$/year),
- c_{3l} annual cost of a third service to join the station at location l (\$/year),
- c_{4l} annual cost of a fourth service to join the station at location l (\$/year),
- c_l^{rec} annual cost of a recruiter at location l (\$/recruiter/year),
- c_{mile} cost per mile of travel (\$/mile),
- c_s^{dist} coefficient for distance cost calculations per service s (\$/recruiter/mile),
- d_{zl} Euclidean distance from the centroid of zip code z to station l
(miles/one-way trip to zip code),
- p_z population of zip code z (people),
- \bar{P}_{sz} recruit production for service s from zip code z (people),
- r_{min} minimum number of recruiters at a station for each service (recruiters),

- r_{max} maximum number of recruiters at a station for each service (recruiters),
 t_s production target for service s (annual accessions),
 ω_s weight for service s proportion of total DoD production (DoD accessions/service accessions), and

Binary Variables:

- U_l one, if station l is open,
 W_l one, if station l is a two service station,
 W'_l one, if station l is a three service station,
 W''_l one, if station l is a four service station,
 X_{sl} one, if station l is occupied by service s , and
 Y_{szl} one, if zip code z is assigned to station l for service s .

Non-negative Variables:

- H_{szl} recruiter share for service s assigned to station l in zip code z (recruiters for zip code z /recruiters at station l).

Integer Variables:

- R_{sl} number of recruiters from service s assigned to station l (recruiters).

2. The Min-Cost MS-LOCAL

The objective function of the min-cost form is to minimize total costs. The primary constraint is a target production level which must be met by each service. The formulation is:

Minimize

$$\sum_l \left[c_{1l}U_l + c_{2l}W_l + c_{3l}W'_l + c_{4l}W''_l + \sum_s \left(c_l^{rec} R_{sl} + c_{mile} \sum_z \left(c_s^{dist} d_{zl} p_z Y_{szl} \right) \right) \right]$$

subject to

$$\sum_z \bar{P}_{sz} \geq t_s \quad \forall s \quad (\text{III.1})$$

$$Y_{szl} \leq X_{sl} \quad \forall s, z, l \quad (\text{III.2})$$

$$\sum_l Y_{szl} = 1 \quad \forall s, z \quad (\text{III.3})$$

$$\sum_z H_{szl} = R_{sl} \quad \forall s, l \quad (\text{III.4})$$

$$X_{sl} \leq U_l \quad \forall s, l \quad (\text{III.5})$$

$$\sum_s X_{sl} - W_l - W'_l - W''_l \leq 1 \quad \forall l \quad (\text{III.6})$$

$$W'_l \leq W_l \quad \forall l \quad (\text{III.7})$$

$$W''_l \leq W'_l \quad \forall l \quad (\text{III.8})$$

$$r_{\min} X_{sl} \leq R_{sl} \quad \forall s, l \quad (\text{III.9})$$

$$r_{\max} X_{sl} \geq R_{sl} \quad \forall s, l \quad (\text{III.10})$$

$$U_l, W_l, W'_l, W''_l, X_{sl}, Y_{szl} \in \{0, 1\} \quad \forall s, z, l$$

$$R_{sl} \in \{0, 1, \dots\} \quad \forall s, l$$

$$H_{szl} \geq 0 \quad \forall s, z, l$$

Constraint set III.1 ensures that the target goals for each service for annual production are met. Constraint set III.2 ensures that zip codes are assigned only to open stations. Constraint set III.3 assigns each zip code to exactly one station for each service. Constraint set III.4 ensures the total amount of recruiter share equals the number of recruiters for each service assigned to a station. Constraint set III.5 ensures the assignment of services to open stations. Constraint sets III.6, III.7, and III.8 enforce appropriate joint station variables. Constraint sets III.9 and III.10 provide for a minimum and maximum number of recruiters per service at a station, respectively.

We make recruiter share a decision variable to model the tendency of a recruiter to spend more time in the most productive zip codes. The variables are descriptive, rather than prescriptive; that is, we do not presume that recruiters should allocate their time according to these variables.

3. The Max-Production MS-LOCAL

The objective function for the max-production form is to maximize total production, the number of A-cell contracts the DoD acquires annually for a given set of zip codes. In order to combine each service's production into one objective function, we give weights to each service. This is necessary because the services differ in overall productivity of stations and recruiters. For example, because the objective is to obtain "DoD recruits", the model might create a disproportionately large number of Air Force recruiters, simply because they are more productive. The weights attempt to achieve a balanced proportion by service. We assign weight ω_s for service s , by the ratio of the service's annual recruiting goal to the total DoD goal. The primary constraint is a budget amount all services must not exceed.

The formulation is:

$$\text{Maximize } \sum_s \sum_z \omega_s \bar{P}_{sz}$$

subject to

$$\begin{aligned} & \sum_l [c_{1l}U_l + c_{2l}W_l + c_{3l}W'_l + c_{4l}W''_l] \\ & + \sum_l \sum_s \left[c_i^{rec} R_{sl} + c_{mile} \sum_z (c_s^{dist} d_{zl} p_z Y_{szl}) \right] \leq B \end{aligned} \quad (\text{III.11})$$

and III.2, III.3, ... , III.10.

Constraint set III.11 ensures that the amount by the services stays within the total recruiting budget.

D. SOLUTION METHODOLOGY

MS-LOCAL is a mixed integer linear programming problem. To obtain solutions with available software, we incorporate a heuristic to obtain integer values for recruiters, and make a simplifying assumption to reduce the size of the problem.

1. Obtaining Integer Recruiters

To solve the two forms of MS-LOCAL, we first relax the integer restriction on the number of recruiters R_{sl} and solve the resulting mixed integer linear program. Next, we fix the station location variables X_{sl} , the zip code assignment variables Y_{szl} , the location indicator variables U_l , and the joint station variables W_l , W'_l and W''_l , and truncate the continuous values associated with the R_{sl} 's. For the min-cost form, this could result in an infeasible integer solution. For the max-production form, the truncation gives a feasible integer solution, because decreasing the total number recruiters cannot violate any constraints, but we may be able to add an additional recruiter to achieve more production.

To deal with the problems of truncation, we solve a small integer program to add the necessary number of recruiters to achieve target production (for the min-cost form) or to achieve additional production within the budget constraints (for the max-production form). The new notation is:

Data:

\bar{R}_{sl} truncated value of continuous number of recruiters of service s assigned to station l (recruiters),

Binary Variable:

R'_{sl} one, if service s adds a recruiter to station l (recruiters).

The min-cost formulation is:

$$\text{Minimize } \sum_{sl} R'_{sl}$$

subject to

$$\sum_z \bar{P}_{sz} \geq t_s \quad \forall s \quad (\text{III.12})$$

$$\sum_z H_{szl} = \bar{R}_{sl} + R'_{sl} \quad \forall s, l \quad (\text{III.13})$$

$$r_{\min} X_{sl} \leq \bar{R}_{sl} + R'_{sl} \quad \forall s, l \quad (\text{III.14})$$

$$r_{\max} X_{sl} \geq \bar{R}_{sl} + R'_{sl} \quad \forall s, l \quad (\text{III.15})$$

$$R'_{sl} \in \{0,1\} \quad \forall s,l$$

Constraint set III.12 ensures that the target goals for each service for annual production are met or exceeded. Constraint set III.13 ensures the total amount of recruiter share equals the new number of recruiters for each service assigned to a station. Constraint sets III.14 and III.15 provide for a minimum and maximum number of recruiters per service at a station, respectively.

The max-production formulation is:

$$\text{Maximize } \sum_s \sum_z \omega_s \bar{P}_{sz}$$

subject to

$$\begin{aligned} & \sum_l [c_{1l}U_l + c_{2l}W_l + c_{3l}W'_l + c_{4l}W''_l] \\ & + \sum_l \sum_s \left[c_{5l} (\bar{R}_{sl} + R'_{sl}) + c_{mile} \sum_z (c_s^{dist} d_{zl} p_z Y_{szl}) \right] \leq B \end{aligned} \quad (\text{III.16})$$

and III.13, III.14 and III.15.

Constraint set III.16 ensures that the amount spent by each service, with their new level of recruiters stays within the funding level.

2. Reducing Problem Size

In order to reduce the problem size (metro areas can have hundreds of zip codes; districts more than 1,000) and obtain good solutions in a modest amount of time, we fix a number of the zip code to station assignment variables Y_{szl} to zero. Specifically, we require that each zip code be assigned to one of its three closest stations only, allowing us to fix the variables representing more distant stations. We believe this is justified, because in practice, it is unlikely that a recruiting area would be willing to undergo more drastic restructuring than that allowed by our assumptions.

IV. IMPLEMENTATION AND RESULTS

We apply the min-cost and max-production forms of MS-LOCAL to three metropolitan areas — Jacksonville, Denver, and Boston — to test the results. We choose metropolitan areas as our unit of study for two reasons: first, the problem size is most suitable, and second, metro areas define common boundaries, whereas Navy districts or Army battalions do not.

We begin by discussing some data issues.

A. DATA

Although MS-LOCAL can address the 4-service problem, we were able to obtain data for the Army and Navy only. The regression model producing values for the coefficients of the production function (see Table II) is built over all zip codes in the United States. These values, therefore, reflect no regional differences in recruiting productivity.

Table III lists coefficients that describe the interaction effects between services. Notice that the effect of Army recruiter share and an Army station in a zip code on Navy production is slightly positive, implying that the presence of an Army station or recruiters in an area actually boosts Navy production. The effect of Navy presence on Army production is also positive, but to a smaller degree. Possible explanations for this result include: The presence of another service may actually boost production, perhaps due to an increase in military presence in the area, or the fact that both services tend to locate in or near the most productive zip codes may bias the result.

Finally, MS-LOCAL requires longitude and latitude for all zip codes. We model distances between zip codes by calculating the Euclidean distance between centroids.

To test MS-LOCAL, we limit the candidate zip codes in which to locate a station to zip codes that currently have an Army or Navy station. For example,

Response Variable	Coefficient - Army	Coefficient - Navy
Intercept	0.015367	0.217295
District/Battalion	0.0	- 0.273450
Fiscal Year	0.007519	0.014216
Quarter	0.0548508	0.0349365
Population	0.0001222	0.000069836
Urban	0.405298	0.309809
Suburb	0.256427	0.152695
Income	- 0.000006040	- 0.000002468
Area	0.000023268	0.000010468
Joint Station	- 0.182186	- 0.093485
Population Density	- 0.000313	- 0.000227
HS1 (one high school)	0.046569	0.035441
HS2 (two or more high schools)	0.359089	0.227864
Share - Income Interaction	- 0.000006415	- 0.000003577
Share - Urban Interaction	- 0.166994	- 0.135289
Share - Suburb Interaction	- 0.174583	- 0.134091
Share - HS1 Interaction	0.043616	0.034449
Share x population	- 0.000019185	- 0.000009237
Station - Population Interaction	- 0.000028653	- 0.000055278
Station - Income Interaction	- 0.000028653	- 0.000017612
Station - Urban Interaction	0.453667	- 0.254568
Station - Suburb Interaction	0.489373	- 0.228859
Station - HS1 Interaction	0.238288	0.189820
Station x population	- 0.000096685	- 0.000055278

Table II. The coefficients for the production function for each of the predictor variables for Army and Navy. The coefficients that vary by service are district/battalion, fiscal year and quarter. Those that vary by service and zip code are population, urban, suburb, income, area, joint station, population density, number of high schools, and the share and station variables that interact with the zip code attributes.

		Army	Navy
Distance to Station on Production	Army	- 0.00405	- 0.000253
	Navy	- 0.000036144	- 0.000106
Service Share on Production	Army	0.442498	0.098993
	Navy	0.015499	0.243849
Service Share Squared on Production	Army	- 0.000424	- 0.003715
	Navy	- 0.002428	- 0.000293
Service Station in Zip Code on Production	Army	0.333482	0.205587
	Navy	0.420893	0.718320

Table III. The coefficients that describe the interaction effects between services for Army and Navy. Notice that the effect of Army recruiter share and an Army station in a zip code on Navy production is slightly positive, implying that the presence of an Army station or recruiter in an area actually boosts Navy production. The effect of Navy presence on Army production is also positive, but to a smaller degree.

the Navy has a station in zip code 32095 in the Jacksonville metropolitan area, but the Army does not. We consider this zip code a candidate for a joint station or a single-service station of either service.

B. RESULTS

We implement MS-LOCAL in the General Algebraic Modeling System (GAMS) (Brooke et al., 1996) and use CPLEX version 5.0 (ILOG, 1999) to solve the mixed-integer linear programming problems. Problem size varies from Jacksonville (7,422 rows and 5,131 variables) to Boston (113,445 rows and 87,841 variables); solutions take from 5 minutes to 3 hours on an IBM RS-6000 model 590 workstation. To allow large problems to finish in a reasonable time, we establish a 2% exit tolerance in GAMS; thus we do not always solve to optimality.

We solve both forms of MS-LOCAL under the \$10K and \$40K scenarios for recruiter cost. The intent is to determine the extent the cost assumption affects the tradeoff between recruiter and station resources. To obtain production goals for the min-cost form of MS-LOCAL, we solve the max-production form with stations and

	Recr. Cost = \$10K			Recr. Cost = \$40K		
	Current Config.	Min Cost	Max Prod.	Current Config.	Min Cost	Max Prod.
Stations	2/1/4	4/2/1	2/0/4	2/1/4	3/1/3	1/1/5
Recr.	32/18/50	32/13/45	42/8/50	32/18/50	33/12/45	41/8/49
Cost	\$676,452	\$607,148	\$674,498	\$2,176,452	\$1,971,722	\$2,147,972
Prod.	118/79	118/79	123/79	118/79	118/79	124/79

Table IV. MS-LOCAL results for the Jacksonville metropolitan area. Entries in the ‘Stations’ row correspond to Army/Navy/Joint stations. Entries for ‘Recr.’ reflect the number of Army/Navy/Total recruiters. Entries in the ‘Cost’ row indicate total recruiting cost for the DoD and ‘Prod.’ entries reflect Army/Navy recruits.

recruiters fixed to the current configuration. MS-LOCAL simply distributes recruiter share and returns production. We use weights $\omega_A = 1$ and $\omega_N = 0.76$ for Army and Navy production respectively (Associated Press, 1998). To establish budget values for the max-production MS-LOCAL, we apply appropriate station and recruiter costs to the current configuration, and estimate travel cost from the distances to zip codes.

We note that Lawphongpanich et al. (1994) report that their approach obtains solutions within 10% of optimality. We use a similar approach to obtain integer values for recruiters in MS-LOCAL and find similar results. The gaps between optimal solutions to the relaxed problem (with continuous recruiters) and the solutions for MS-LOCAL are within 8% for both the min-cost and max-production forms.

1. Jacksonville

The Jacksonville metropolitan area consists of 52 zip codes with 7 recruiting station locations and 11 stations. Figure 3 shows the current configuration consisting of 2 Army stations, 1 Navy station, and 4 Joint stations. Figure 4 and Table IV show the results of MS-LOCAL.

As required, the min-cost solutions reach the same production goal as the current configuration, but do so at approximately a 10% savings in cost. For recruiter cost equal to \$10K, there are fewer total stations, and the average number of recruiters

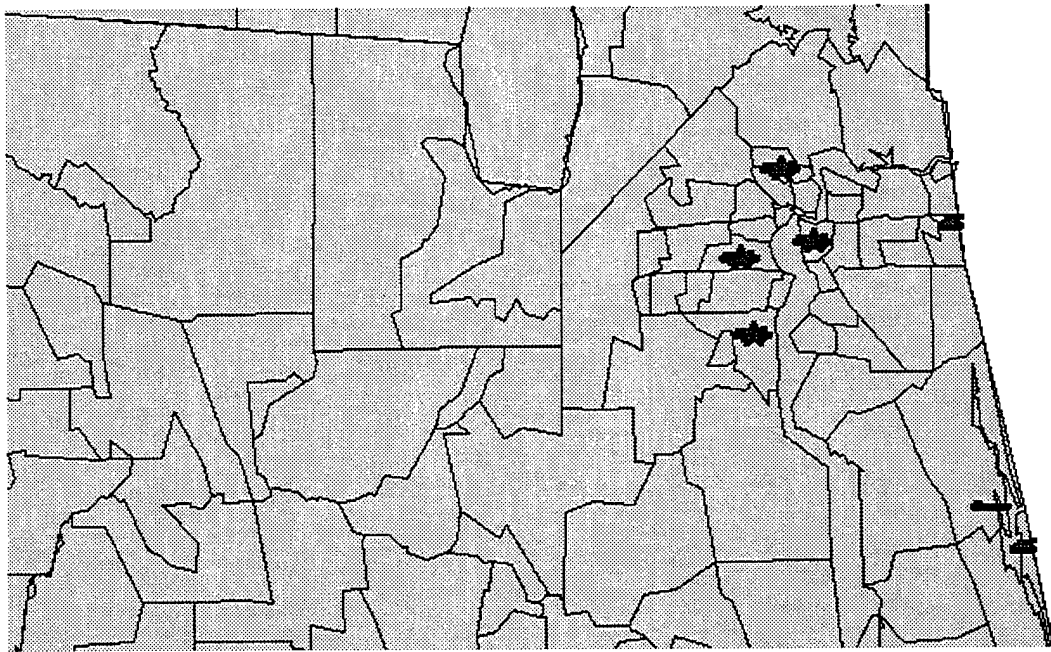


Figure 3. The current configuration for Army and Navy recruiting stations in Jacksonville. The Army, Navy and Joint stations are represented by tanks, ships and a star overlay, respectively.

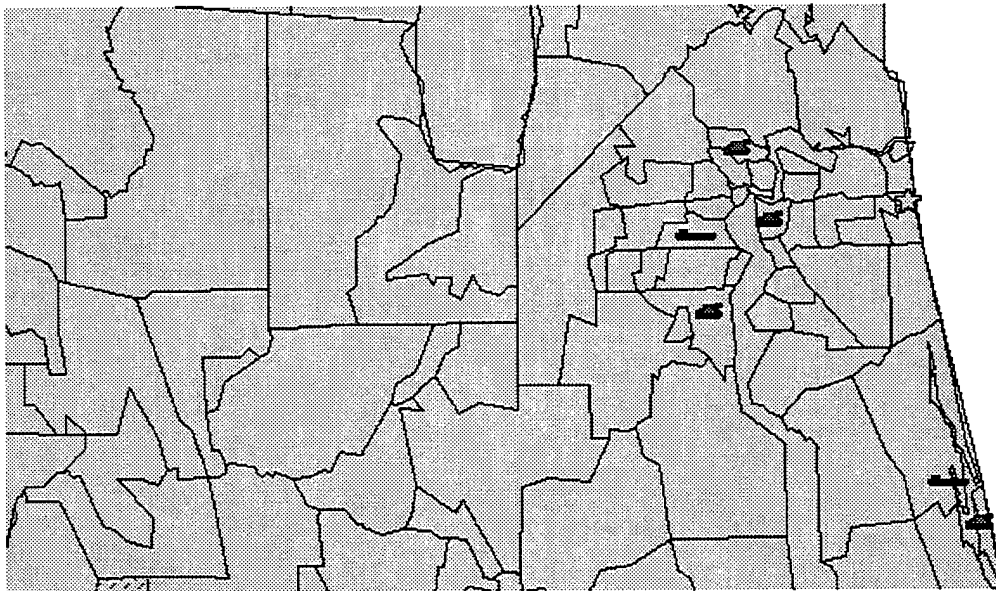


Figure 4. The configuration recommended by the min-cost form of MS-LOCAL for Jacksonville (Recruiter Cost = \$10K). The Army, Navy and Joint stations are represented by tanks, ships and a star, respectively. The solution represents three fewer stations than the current configuration.

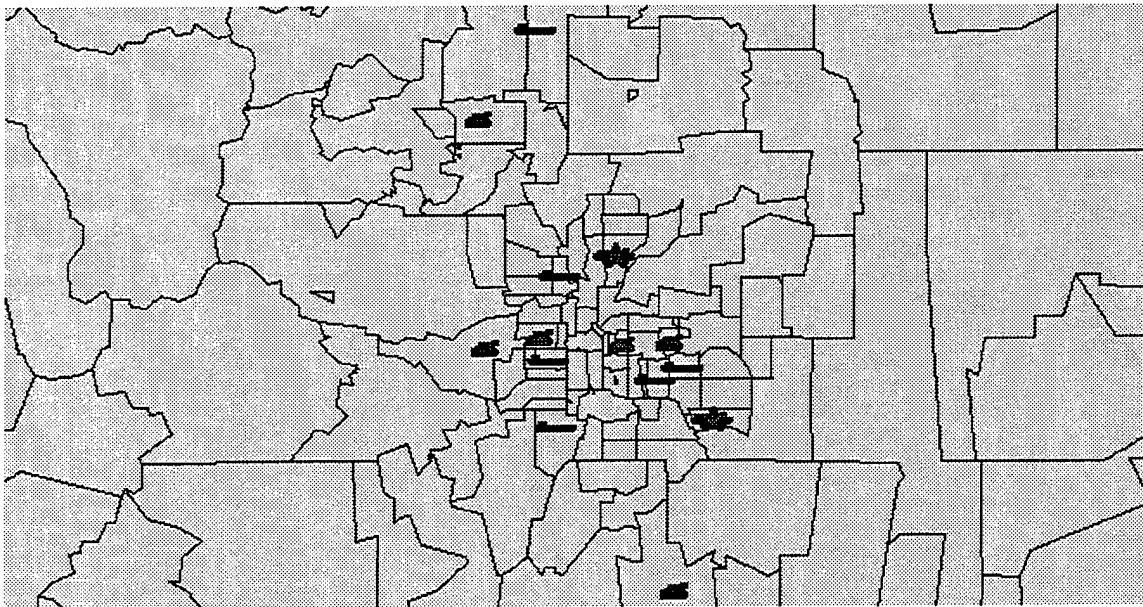


Figure 5. The current configuration for Army and Navy recruiting stations in Denver. The Army, Navy and Joint stations are represented by tanks, ships and stars, respectively.

per station is 6.4, up from 4.6 for the current configuration. At recruiter cost \$40K the solution recommends one more station, and, surprisingly, the same number of recruiters. This solution does have more joint stations.

The max-production form produces only 2.4% and 2.9% more recruits for the \$10K and \$40K cases, respectively. This solution favors joint stations even more than the solution to the min-cost form.

2. Denver

The Denver metropolitan area consists of 104 zip codes with 14 station locations housing 16 stations—6 Army, 6 Navy, and 2 Joint (see Figure 5). Figure 6 and Table V show the results of MS-LOCAL. Table V shows savings of 12.7% and 13.6% for the min-cost form using the two recruiter costs. Unlike the Jacksonville solutions, the solutions for Denver suggest more joint stations for the case of \$10K recruiter cost than for \$40K.

The max-production solutions increase production by 3.2% and 1.6% for the

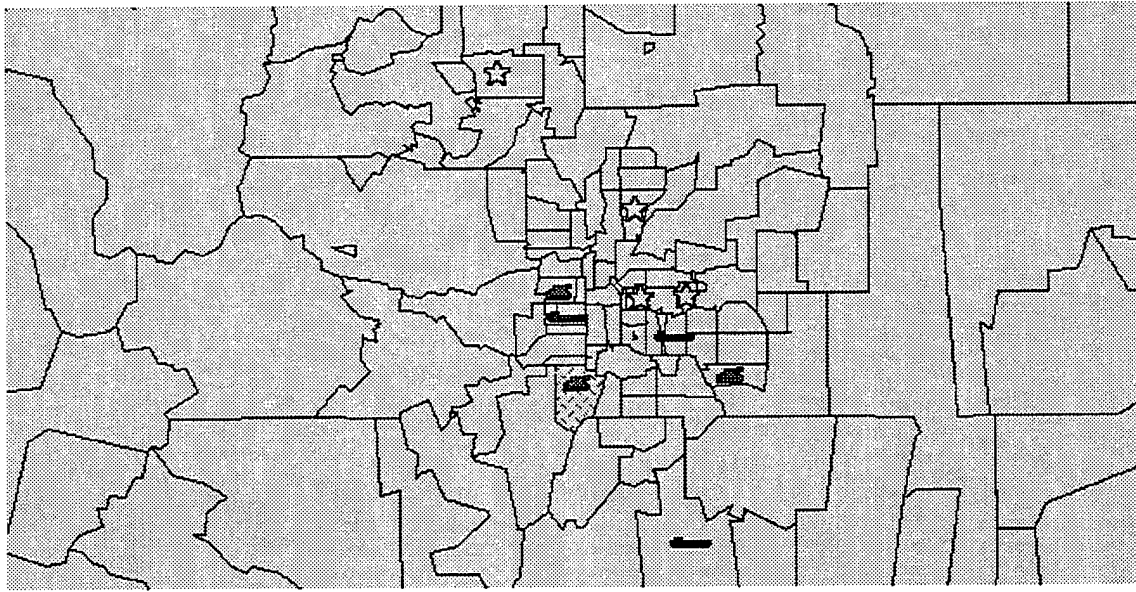


Figure 6. The configuration recommended by the min-cost form of MS-LOCAL for Denver (Recruiter Cost = \$10K). The Army, Navy and Joint stations are represented by tanks, ships and stars, respectively. The solution represents two fewer stations than the current configuration.

	Recr. Cost = \$10K			Recr. Cost = \$40K		
	Current Config.	Min Cost	Max Prod.	Current Config.	Min Cost	Max Prod.
Stations	6/6/2	3/3/4	2/1/6	6/6/2	6/5/2	1/0/8
Recr.	30/31/61	32/11/43	56/7/63	30/31/61	33/19/52	52/8/60
Cost	\$894,026	\$780,687	\$886,731	\$2,724,026	\$2,354,468	\$2,697,948
Prod.	187/127	187/127	200/124	187/127	187/127	197/122

Table V. MS-LOCAL results for the Denver metropolitan area. Entries in the 'Stations' row correspond to Army/Navy/Joint stations. Entries for 'Recr.' reflect the number of Army/Navy/Total recruiters. Entries in the 'Cost' row indicate total recruiting cost for the DoD and 'Prod.' entries reflect Army/Navy recruits.



Figure 7. The current configuration for Army and Navy recruiting stations in Boston. The Army, Navy and Joint stations are represented by tanks, ships and a star overlay, respectively.

two recruiter costs respectively. When recruiter costs equal \$40K, there is an expected increase in the number of stations and a decrease in the number of recruiters. Both max-production solutions recommend joint stations overwhelmingly.

3. Boston

The Boston metropolitan area consists of 261 zip codes, 24 station locations, and 32 Army and Navy stations. Figure 7 shows the current configuration; Figure 8 and Table VI show the results of MS-LOCAL.

Table VI shows that the Boston metropolitan area can reach the same production as the current configuration but at a 29.7% and 32.4% savings in cost, respectively for the two different recruiter costs. These savings are associated with a significant reduction in the number of stations and recruiters, and are much larger than in the Jacksonville and Denver cases. The max-production results shown in Table VI show an increase in annual recruits of 5.9% and 7.8%, respectively for the two recruiter



Figure 8. The configuration recommended by the min-cost form of MS-LOCAL for Boston (Recruiter Cost = \$10K). The Army, Navy and Joint stations are represented by tanks, ships and a star, respectively. The solution represents an estimated 29.7% reduction in cost.

	Recr. Cost = \$10K			Recr. Cost = \$40K		
	Current Config.	Min Cost	Max Prod.	Current Config.	Min Cost	Max Prod.
Stations	11/5/8	10/9/2	2/3/12	11/5/8	6/6/7	4/7/9
Recr.	59/40/99	38/22/60	56/7/63	59/40/99	43/20/63	77/21/98
Cost	\$1,539,984	\$1,082,973	\$1,532,141	\$4,509,984	\$3,047,546	\$4,490,926
Prod.	311/238	311/238	338/244	311/238	311/238	348/244

Table VI. MS-LOCAL results are shown for the Boston metropolitan area. Entries in the 'Stations' row correspond to Army/Navy/Joint stations. Entries for 'Recr.' reflect the numbers of Army/Navy/Total recruiters. Entries in the 'Cost' row indicate total recruiting cost for the DoD and 'Prod.' entries reflect Army/Navy recruits.

Metro area	Min-cost		Max-prod	
	\$10K	\$40K	\$10K	\$40K
Jacksonville	25	60	80	83
Denver	57	27	80	94
Boston	17	54	83	62

Table VII. The percent of stations that MS-LOCAL recommends for collocation. The max-production form favors collocation much more than the min-cost form. This is likely due to the positive interaction effect of having a station of the other service in a zip code. The max-production form seeks these marginal gains in production, while the min-cost form needs only to satisfy a production constraint.

costs, again much larger increases than for the other metro areas.

We believe the Boston results are better because the current configuration has too many stations in the suburbs. The current configuration locates the majority of its joint stations towards the outer boundaries of the metro area; however, the min-cost solution locates just two joint stations in the downtown Boston area. For example, there is currently a joint station with 5 Army and 3 Navy recruiters in suburban zip code 03103; the min-cost solution makes this a Navy station with 2 recruiters.

C. FINDINGS

In general, our results show that a combination of single-service and joint stations is most effective in minimizing cost and maximizing production. The results do not seem to suggest that a certain portion of stations should be joint across all metro areas (see Table VII). The max-production solutions favor collocation much more than do the min-cost solutions for our 3 test cases. This is likely due to the positive interaction effect of having a station of the other service in a zip code. The max-production form seeks these marginal gains in production, while the min-cost form needs only to satisfy a production constraint.

Surprisingly, when recruiter cost increases from \$10K to \$40K, MS-LOCAL

	Current Configuration	Recruiter Cost = \$10K		Recruiter Cost = \$40K	
		Minimum Cost	Maximum Production	Minimum Cost	Maximum Production
Jacksonville	4.6	6.4	5.0	4.5	4.1
Denver	3.8	3.1	4.2	3.5	3.5
Boston	3.1	2.5	3.5	2.4	3.4

Table VIII. Average Number of Recruiters per Station. Each row shows, for both recruiter cost values, the average number of recruiters for the current configuration and the min-cost and max-production trials for each metropolitan area.

does not consistently recommend fewer recruiters. In 3 of 6 cases the cost increase leads to slightly fewer recruiters, in 2 cases it leads to more recruiters, and in 1 case no change. In 4 of 6 cases, solutions recommend more collocation when the cost of a recruiter is higher.

We also observe that as the size of the metropolitan area increases, the average size of the recruiting station (measured in the number of recruiters per station) decreases (see Table VIII). We believe this issue warrants more careful study before making conclusions, because for our case studies we took the candidate locations for MS-LOCAL from the current configuration. This, and the fact that we require that each zip code be assigned to one of its 3 closest stations, will tend to produce new configurations similar to existing ones.

Finally, we note that for almost all trials, the number of Army recruiters is greater than the number of Navy recruiters. We expect this because the input production targets (for the min-cost form) and weights (for the max-production form) require a higher level of production for the Army. Also, the production model indicates that the Navy benefits more from the presence of an Army recruiter than the Army does from a Navy recruiter. Thus, in general, the Navy need not allocate as many recruiters in common areas as the Army in order to achieve similar production.

V. SUMMARY AND CONCLUSIONS

This thesis addresses the problem of determining, within a given region, the locations of recruiting stations and the number of recruiters of each service to assign to each station. We present a model (MS-LOCAL) in two forms, one that seeks the least cost configuration of stations and recruiters, such that each service achieves its annual production goal for enlisted recruits, and another that seeks to maximize the number of recruits, subject to a budget constraint.

Since mixed integer non-linear programming problems are known to be difficult to solve, we modify the problem to incorporate a piecewise linear approximation of the quadratic production function and a small integer program heuristic to achieve an integer number of recruiters.

Both forms of MS-LOCAL produce results that are relatively close to each other in the number of stations to be located in the metropolitan areas reviewed, but in general, the max-production form recommends more joint stations. The max-production form also tends to achieve additional recruits with more recruiters, rather than by establishing more stations. In all cases, both forms of MS-LOCAL improve over the current configuration of our case study metro areas: the min-cost form reaches the required production goals at a lower cost and the max-production form reaches higher production.

Our analysis does not lead to a conclusion on the "right" level of collocation between services. However, we do observe that the max-production form of MS-LOCAL greatly favors collocated stations. We suspect that configurations will differ significantly depending on zip code characteristics, production goals for each service, and even region of the country. We recommend more case studies on this issue.

MS-LOCAL has several potential uses for DoD.

- The Joint Recruiting Facilities Committee can use MS-LOCAL to help decision-makers in joint planning conferences. There is currently no analytical model

to assist in joint location decisions.

- Individual services can use MS-LOCAL to locate stations in a region. Unlike models developed in the past, MS-LOCAL accounts for the locations of other services in estimating production.
- MS-LOCAL can select the best sites for new stations among a set of candidate locations. A weakness of MS-LOCAL is that the user must provide a list of candidate sites. While it is possible to list all zip codes in a region as candidates, such a strategy would most often lead to problems that are too large to solve.
- A strategic use of MS-LOCAL can be to analyze numerous metropolitan areas and classify them by how far each is from the optimal configuration. This would help prioritize regions for further in-depth station analysis.
- MS-LOCAL can address broader policy questions, such as the best number of recruiters per station.

There are several areas possible for more research. First, one can apply MS-LOCAL to more metro areas in order to make more general observations about station size versus metro size, level of collocation, and the effects of one service on another. Second, our research concerns only the Army and Navy. One can incorporate data for the Air Force and Marines and make more general statements about collocation (and degree of collocation) and the interaction between services. Third, MS-LOCAL requires as input a production or budget level. An aggregate model to solve the country level problem would be useful to establish the best budget- and production-allocations for regions.

LIST OF REFERENCES

- Achabal, D. D., W. L. Gorr and V. Mahajan, "MULTILOC: A Multiple Store Location Decision Model," *Journal of Retailing*, v. 58(2), pp. 5-25, Summer 1982.
- Associated Press, "Military Recruiters Are Coming Up Short Despite Refining Techniques," *St. Louis Post-Dispatch*, 08 December 1998.
- Bazaraa, M. S., H. D. Sherali, and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms*, 2nd ed., John Wiley & Sons, Inc., New York, 1993.
- Bohn, D. A. and E. J. Schmitz, "Station Location Analysis", Research Report, Navy Recruiting Command, 1992.
- Brooke, A., D. Kendrick and A. Meeraus, *GAMS Release 2.25 - A User's Guide*, 2nd ed., GAMS Development Corporation, Washington, D.C., 1996.
- Celski, R. J., "Realignment of the U. S. Army Recruiting Command", Master's thesis, Naval Postgraduate School, Monterey, California, September 1992.
- Current, J. R. and J. E. Storbeck, "A Multiobjective Approach to Design Franchise Outlet Networks," *Journal of the Operational Research Society*, v. 45(1), pp. 71-81, 1994.
- Doll, J. M., "An Optimal Allocation of Recruiters and Facilities in the 12th Marine Corps District", Master's thesis, Naval Postgraduate School, Monterey, California, March 1992.
- Domich, P. D., K. L. Hoffman, R. H. F. Jackson, and M. A. McClain, "Locating Tax Facilities: A Graphics-Based Microcomputer Optimization Model," *Management Science*, v. 37(8), pp. 960-979, August 1991.
- Eiselt, H. A., G. LaPorte, and J. Thisse, "Competitive Location Models: A Framework and Bibliography," *Transportation Science*, v. 27(1), pp. 44-54, February 1993.
- General Accounting Office, Military Recruiting: More Innovative Approaches Needed, December 1994.
- Ghosh, A. and C. S. Craig, "FRANSYS: A Franchise Distribution System Location Model," *Journal of Retailing*, v. 67(4), pp. 466-495, Winter 1991.
- Hogan, P. F., J. Hughes, S. Mehay, and M. Cook, "Enlistment Supply at the Local Market Level," presented at the Western Economic Association International Annual Meeting, June 1998.

Hogan, P. F, E-mail between P. F. Hogan, Vice President, The Lewin Group, and K. R. Gue, September 1998a.

Hogan, P. F, E-mail between P. F. Hogan, Vice President, The Lewin Group, and K. R. Gue, November 1998b.

ILOG, CPLEX Products, [<http://www.ilog.com/products/cplex/>]. March 1999.

Lawphongpanich S., R. E. Rosenthal and CAPT G. Schwartz, "Location-Allocation Model for Naval Recruiting Stations (New Jersey and New York Districts)", Interim Report to the Navy Recruiting Command, Naval Postgraduate School, Department of Operations Research, Monterey, California, 1992.

Lawphongpanich S., So Young Sohn, and CPT M. J. Teague, "Optimal Realignment of U.S. Army Recruiting Stations", Report to the Army Recruiting Command, Naval Postgraduate School, Department of Operations Research, Monterey, California, 1994.

Myers, S. L., "Young People Choosing Fun Over Being All They Can Be," *New York Times*, 03 November 1998.

Nakanishi, M., and L. G. Cooper, "Parameter Estimate for Multiplicative Competitive Interactive Model - Least Squares Approach," *Journal of Marketing Research*, v. 11, pp. 303-311, August 1974.

Office of the Assistant Secretary of Defense (Force Management Policy), Study of a Joint Process for Determining the Location of Recruiting Stations, Second Interim Report to the House Committee on National Security, Senate Committee on Armed Services and House and Senate Committees on Appropriations, November 1996a.

Office of the Assistant Secretary of Defense (Force Management Policy), Population Representation in the Military Services: Fiscal Year 1996, 23rd Annual DoD Report on Social Representation in the U.S. Military Services, 1996b.

Pirkul, H., S. Narasimhan, and P. De, "Firm Expansion Through Franchising: A Model and Solution Procedures," *Decision Sciences*, v. 18, pp. 631-644, 1987.

Schwartz, G. S., "Realigning the U. S. Navy Recruiting Command", Master's thesis, Naval Postgraduate School, Monterey, California, March 1993.

Soutter, P., E-mail between P. Soutter, Forecasting and Goaling Branch, Navy Recruiting Command and author, March 1999.

Zeller, R. E., D. D. Achabal, and L. A. Brown, "Market Penetration and Locational Conflict in Franchise Systems," *Decision Sciences*, v. 11, pp. 58-80, 1980.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
 8725 John J. Kingman Rd., STE 0944
 Ft. Belvoir, Virginia 22060-6218

2. Dudley Knox Library 2
 Naval Postgraduate School
 411 Dyer Rd.
 Monterey, California 93943-5101

3. Paul E. Martin 1
 899 Viewmont Avenue
 Johnstown, Pennsylvania 15905

4. Dr. Kevin R. Gue 3
 Systems Management Department (Code SM/Gk)
 Naval Postgraduate School
 555 Dyer Rd.
 Monterey, California 93943-5103

5. Dr. Robert F. Dell 1
 Operations Research Department (Code OR/De)
 Naval Postgraduate School
 1411 Cunningham Rd.
 Monterey, California 93943-5219

6. Commander, Navy Recruiting Command 1
 801 North Randolph Street
 Arlington, Virginia 22203-1991

7. Commander, US Army Recruiting Command 1
 FT Knox, Kentucky 40121